A SENIOR MANUFACTURING LABORATORY FOR DETERMINING INJECTION MOLDING PROCESS CAPABILITY

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KEY WORDS: process capability, quality control, statistical process control, parametric study, control charts.

PREREQUISITE KNOWLEDGE: This subject material is directed at an upper level undergraduate/graduate student in an Engineering or Engineering Technology program. It is assumed that the student has a thorough understanding of the process and quality control. The format of this laboratory does not follow that recommended because of the nature of process capability and that of the Sandretto injection molding equipment and tooling. This laboratory is instead developed to be used as a point of departure for determining process capability for any process in either a quality control laboratory or a manufacturing environment where control charts, process capability, and experimental or product design are considered important topics.

OBJECTIVES: To demonstrate the typical procedure by which one can determine process capability. To demonstrate the development of control charts. To statistically show the areas through which processing variation can enter into the manufacturing process.

EQUIPMENT AND SUPPLIES: A laboratory size injection molder (Sandretto, Spectrum 60) with an ASTM test bar fixture in place with associated machine instrumentation. DataMyte Model 862 with an associated statistics package for generating pareto analysis, control charts, process capability indices, and measuring equipment interfaced with an appropriate software package, Monsanto ABS materials and a hopper dryer for materials control.

Introduction

Spiring (1991) has indicated that interest in process capability is growing, due partly to the changing philosophy in quality control. Motivational tools such as slogans about doing things right the first time and building a better quality product are lost if there is little or no analytical study of the process and the product. World wide competition is forcing everyone (not just the U.S.) to look at how variation in the process and product can be reduced, and how all personnel from design through manufacturing can be involved in the overall effort of reducing variation.

Process capability has been defined as the range over which the output of a process varies or the actual process spread ($6\ \sigma$). Process capability ties both the product and process together. Process capability and the associated indices have the potential to positively impact product design, setting of tolerances or specifications, vendor quality surveys, communication with suppliers, machine allocation and others. Process capability makes it possible to quantify what the process is

capable of doing, which determines if the product can be made to current or revised, possibly tighter specifications.

The following paper is divided into three subsections which lead to determining the process capability of the injection machine. It should be noted that although injection molding is a generic process, determining process capability from one machine to the next may vary considerably.

Sandretto Injection Press/Materials

The machine utilized in the capability study was a Sandretto model Spectrum 60 screw injection molder capable of a 3.17 ounce shot weight and 66 ton clamp capacity. The Sandretto was a new purchase and is considered to be a state of the art machine. Principal operation is at a control panel where virtually all processing characteristics are accessed and manipulated via a microprocessor. Processing characteristics can be seen in either tabular or graphical formats.

Injection molding is a process of molding solid plastic objects. It involves forcing molten plastic into a closed cooled mold where the plastic solidifies to a usable product upon closing.

Parameters were set according to manufacturers' data sheets of the material (Monsanto Cycolac ABS grade z80) being used. These parameters included; drying time, drying temperature, barrel temperature, nozzle temperature, injection speed, and screw plasticizing speed (RPM's).

Control Charts

To determine process capability it is assumed that a robust quality control program has been in place and is working. Control charts are being used and have been successful at removing most if not all assignable error. Juran (1980) states that a control chart is a graphic comparison of process performance data to computed "control limits" drawn as limit lines on the chart. The process performance data usually consist of rational subgroups sampled and plotted sequentially. Process variations are traceable to two kinds of causes: (1) random, i.e., due solely to chance; and (2) assignable, i.e., due to specific "findable" causes (Juran 1980). Only random causes of variation should exist because this represents the minimum amount of variation present ($\overline{X} \pm 3\ \sigma$) in the process. The process is then said to be in a state of statistical process control. The actual process spread is 6 σ which represents the width of the interval that contains 99.73% of the population.

Different types of control charts exist for both attribute and variable process data. Bothe (1991) states that current accepted practices for determining process capability are defined for only variable data. This capability study used $\overline{X}$ and R charts before determining process capability.

Process Capability

Many different indices exist for measuring process capability (Cp, Cr, Cpk). Bothe (1991) contends that this knowledge is extremely useful for shop personnel in determining what machines should be scheduled to run what parts and for monitoring process improvements by seeing these capability indices increase over time. Worthy (1991) indicates that the Japanese use process capability as a design tool to make sure that the intended design can be made to specifications. He also contends that in the U.S. we design the product without regard to whether or not manufacturing is capable of producing the part.

Control charts use rational subgroups with upper and lower control limits

calculated from the subgroups. Tolerances should not be used with control charts; tolerances are for individual items and are typically set independent of the process and may not relate well to process control chart averages. Process capability and the associated indices work with individual items and thus work well with tolerances. One of three situations exists relative to process capability and tolerances where 6σ equals the process capability and U - L equals the difference between upper and lower tolerances.

1. $6\sigma < U - L$ (Figure 1) This represents the most desired relationship. The process is in control and the tolerance is greater than the process capability. Even if there is a shift in the process average, no nonconforming products are likely to be produced since the parts may be considered out of control but conform to specified tolerances.
2. $6\sigma = U - L$ (Figure 2) Process capability is equal to the tolerance. As long as this situation holds, no non-conforming product will be produced. As soon as the process shifts up or down, nonconforming product will be produced. Either processing variation must be reduced or tolerances must be increased.
3. $6\sigma > U - L$ (Figure 3) This is the most undesirable of the three scenarios. Nonconforming product from both extremes of the normal distribution may occur. If a process shift occurs large quantities of nonconforming product may result (Besterfield 1990).

Various capability indices exist, thereby inviting comparisons among processes with different quality variables and promoting similar inferences regardless of the product or quality characteristic measured (Spiring 1991).

Cp - Capability index. A minimum value of 1.33 is recognized as a defacto standard.

Where: $Cp = U - L/6\sigma$

If $Cp = 1.00$ then scenario #2 from above.
If $Cp > 1.00$ then scenario #1 from above.
If $Cp < 1.00$ then scenario #3 from above.

Cr - Capability ratio. The defacto standard for a Cr is 0.75.

Where: $Cr = 6\sigma/U - L$

Cpk - This is used to determine if the process is centered on the target or nominal value. A minimum value of 1.00 is recommended.

Where: $Cpk = Z\,(Min)/3$
$Z\,(U) = U - \overline{X}/\sigma$
$Z\,(L) = \overline{X} - L/\sigma$

Process Capability Procedure

The Sandretto was programmed to print out thirty different process parameters following each shot (Table 1). Each data sheet and corresponding part were labeled to maintain traceability characteristics. Subsequent development of $\overline{X}$ and R control charts followed using select processing variables.

The design of the process capability experiment included but was not limited to:

1. Selection of a suitable molding tool.
   Will the product have subsequent use, i.e., materials characterization, etc..?
   Would the tool be suitable for control charts and process capability studies? (Figure 4) (ASTM D647-90).
2. Design fixture for impact disc.
   Measuring tools available

Data collection (DataMyte)
Statistics and software used (SPCII)
Traceability features
Environmental soaking of fixture and related tooling

3. Develop and build fixture.
4. Develop Iskikawa diagrams of process.(Figures 5 & 6)
   A. Processing parameters.
   B. Machine components.
   C. Material handling.
5. Selection of material.
6. Determine Sandretto settings based on material selection and study.
   A. Barrel heats.
   B. Mold closing.
   C. Mold opening.
   D. Hydraulic ejection.
   E. Injection.
   F. Plasticizing.
7. Determine if process is in control through the use of $\overline{X}$ and R charts.(Figure 7)
   A control chart distinguishes between random and assignable causes of variation through its choice of control limits. These are calculated from the laws of probability in such a way that highly improbable random variations are presumed to be due not to random causes, but to assignable causes (Juran 1980). If points on the graph exceed the established control limits, chances are that assignable causes entered the process and the process should be investigated. Injection molding Hydraulic Pressure points one and five are "out of control". These two points should be investigated. However the remaining points are within our control limits signifying that only random causes are present and the process should be left alone. Each point on a control chart represents a test of hypothesis, but the chart simplifies the calculations and presents a graphic method for doing hypothesis testing continuously (Juran 1980).
8. Determine process capability for select processing characteristics.

Conclusions

This study was initially conceived in and intended to be used in an applied quality control class with an associated laboratory. Various aspects of this study have already been incorporated into the applied quality course and other "non quality control" classes. Determining process capability is an excellent tool for integrating undergraduate/graduate students from electronics to manufacturing, inclusive of the design and mechanical options. The applied study reinforces those manufacturing concepts of the quality philosophy, metrology and statistics as discussed in the classroom. The impact of slight or even dramatic changes in personnel, machines, materials and methods can be graphically determined by using control chart theory and applications. The students need to be aware of this cause and effect taking place in virtually any manufacturing environment. Process capability encourages the synthesis of design of experiments, metrology, statistics, fixture design and use, materials characterization, bench marking, defect concentration analysis, sampling, and process variation to name a few. This study represents a benchmark for future studies scheduled at regular intervals to determine changes in processing parameters and subsequent changes to process capability.

Recommendations

Even though we have only begun this series of studies it is clear that process

capability can be done on virtually any piece of industrial equipment available. The benefits far outweigh the time invested from both the students and faculty members standpoint. As with any scientific study my recommendations are:

* Have a good understanding of statistical process control for all students and faculty involved.
* Provide adequate time for development of study.
* Select equipment with process capability in mind.
* Consider larger picture of process control with process capability being a smaller entity, i.e., spinoffs to other courses.
* Additional work with identifying and reducing sources of variation.

Personnel	Machine
Materials	Methods

* Incorporation of various types of measuring instruments.
* Industry cooperation.

References

ASTM - D647, Design of Molds for Test Specimens of Plastic Molding Materials, 1990 Annual Book of ASTM Standards, Philadelphia, PA.

Besterfield, Dale H. Quality Control, Prentice Hall, Englewood Cliffs, NJ, 1990.

Bothe, Davis R. A Capability Study for an Entire Product. ASQC Annual Quality Proceedings. Milwaukee, WI. May 1991.

Juran and Gryna, Quality Planning and Analysis, McGraw-Hill, Inc., NY, 1980.

Spiring, Fred A. The Cpm Index, Quality Progress, February 1991.

Worthy, Ford S. Japan's Smart Secret Weapon, Fortune, August 12, 1991.

Plasticising End Position (Dose)	32.0 %
	55.0 %
Plasticising Actual Time	11.9 s
Injection 1st Stage Actual Time	1.6 s
(Previous) Overall Cycle Time	26.2 s
Mold Closing Stages Actual Time	2.4 s
Cooling Actual Time	15.0 s
Mold Opening Stages Actual Time	1.4 s
Actual Time of Consents Awaiting Stages by Robot	0.0 s
Carriage Approach Actual Time	0.0 s
Ejector Sequence Actual Time	0.0 s
Hydraulic Ejection Sequence Actual Time	1.0 s
Actual Dwell Time Break	0.1 s
Injection Hold on Stage Actual Time	4.4 s
Actual Hydr. Barrel Pressure at 2nd Injec. Stage Change OV	1117 psi
Screw Actual Position at the Change Over Point	4.9 %
Cushion Final Position	2.8 %
Actual Viscosity Index	554 psi
Actual Nozzle Temperature	444 °F
Zone 'A' Actual Temperature	427 °F
Zone 'B' Actual Temperature	401 °F
Zone 'C' Actual Temperature	348 °F
Zone 1 Actual Conditioning Temperature	863 °F
Zone 2 Actual Conditioning Temperature	855 °F
Real Melt Temperature at Holding Start	446 °F
Average Mold Temperature at Holding Start	859 °F
Obtainable Linear Shrinkage Maximum Limit	0.00 %
Obtainable Linear Shrinkage Minimum Limit	0.00 %
Holding Pressure Optimized Duration	***.** s
Cooling Optimized Duration	***.** s
Maximum pressure in Hydraulic Cylinder From Injection Star	0 psi

TABLE 1. Process Parameters Available From Each Cycle of Sandretto Injection Molding Machine

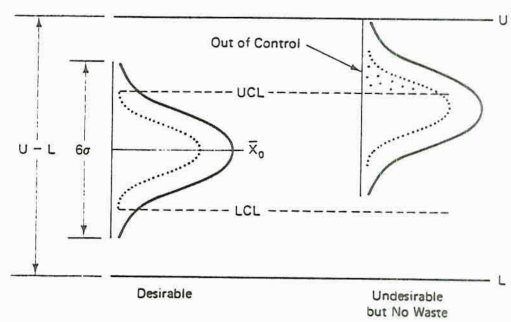

FIGURE 1. $6\sigma < U - L$

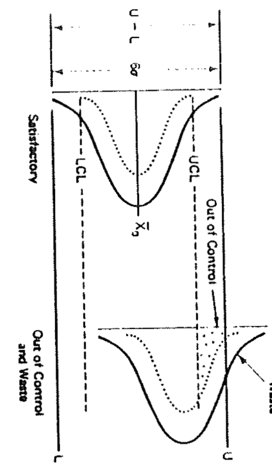

FIGURE 2. 6 σ = U - L

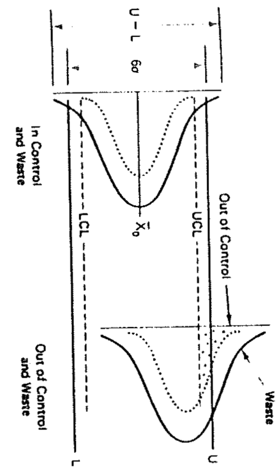

FIGURE 3. 6 σ > U - L

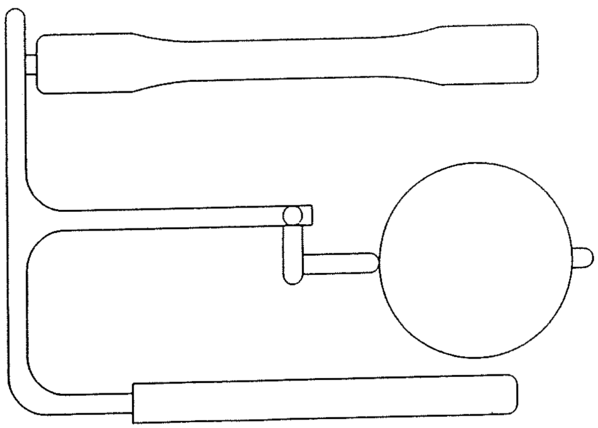

FIGURE 4. ASTM Test Fixture

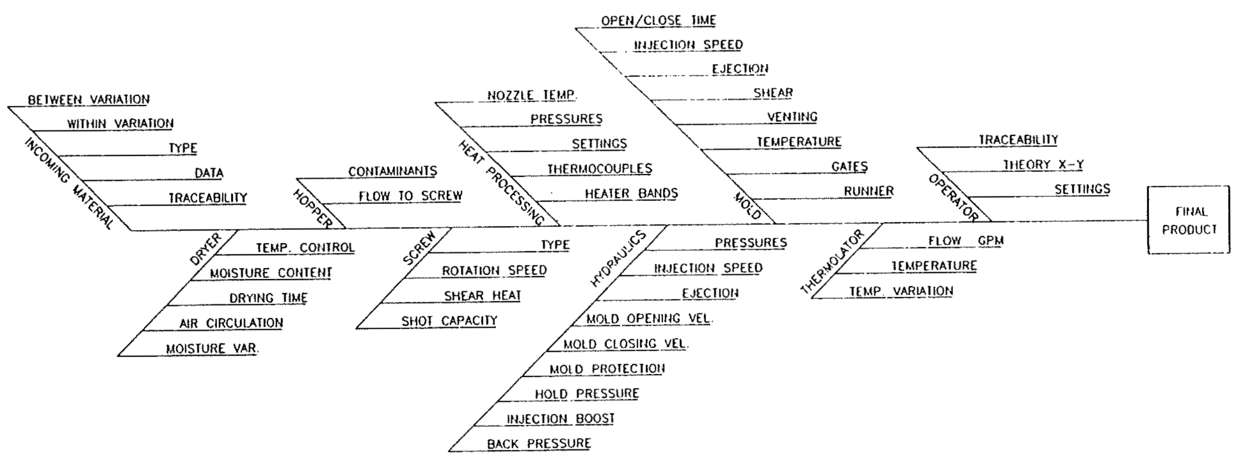

FIGURE 5. Iskikawa Diagram of Various Injection Molding Inputs

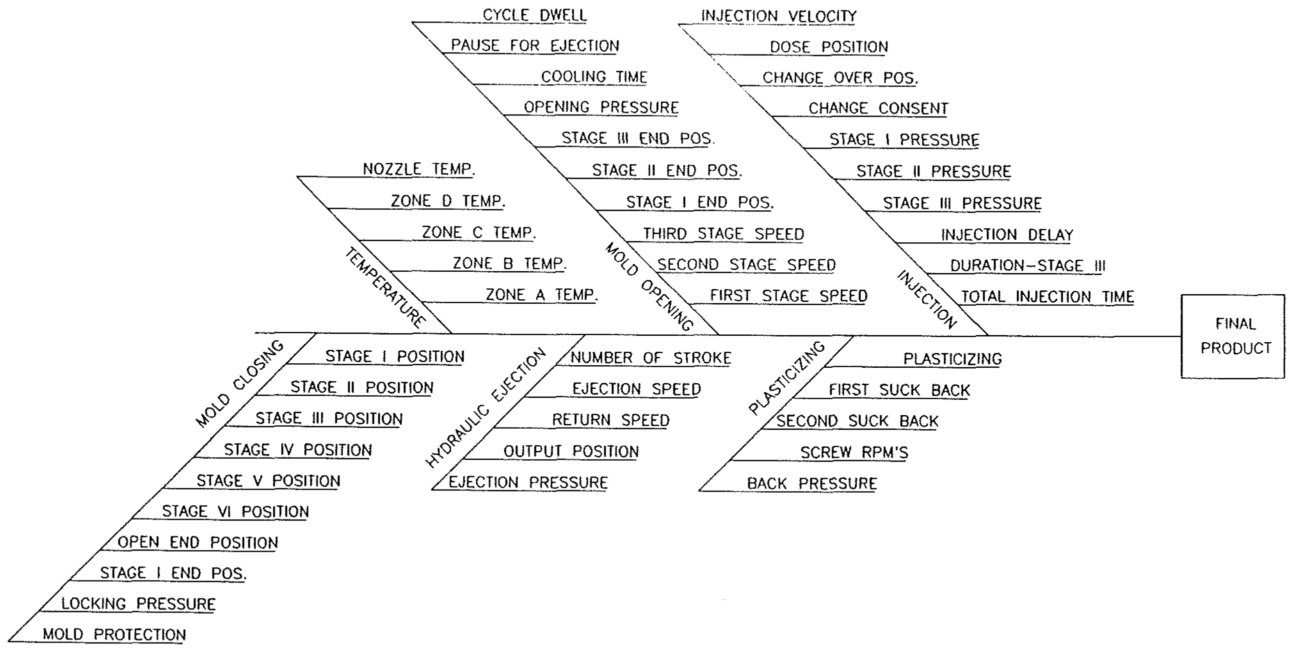

FIGURE 6. Iskikawa Diagram of Processing Characteristics

SUBGROUP	1	2	3	4	5	6	7	8	9	10
SIZE	5	5	5	5	5	5	5	5	5	5
UCL	1113.105	1113.105	1113.105	1113.105	1113.105	1113.105	1113.105	1113.105	1113.105	1113.105
LCL	1101.455	1101.455	1101.455	1101.455	1101.455	1101.455	1101.455	1101.455	1101.455	1101.455
MEAN	1118.200	1110.400	1106.600	1105.000	1099.800	1106.000	1104.200	1106.000	1107.600	1109.000
RANGE	10.000	15.000	12.000	8.000	10.000	8.000	5.000	13.000	11.000	9.000
IN CONTROL?	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES
RUN TESTS	1				1					
DATE / TIME	10/10/91									
COMMENT										

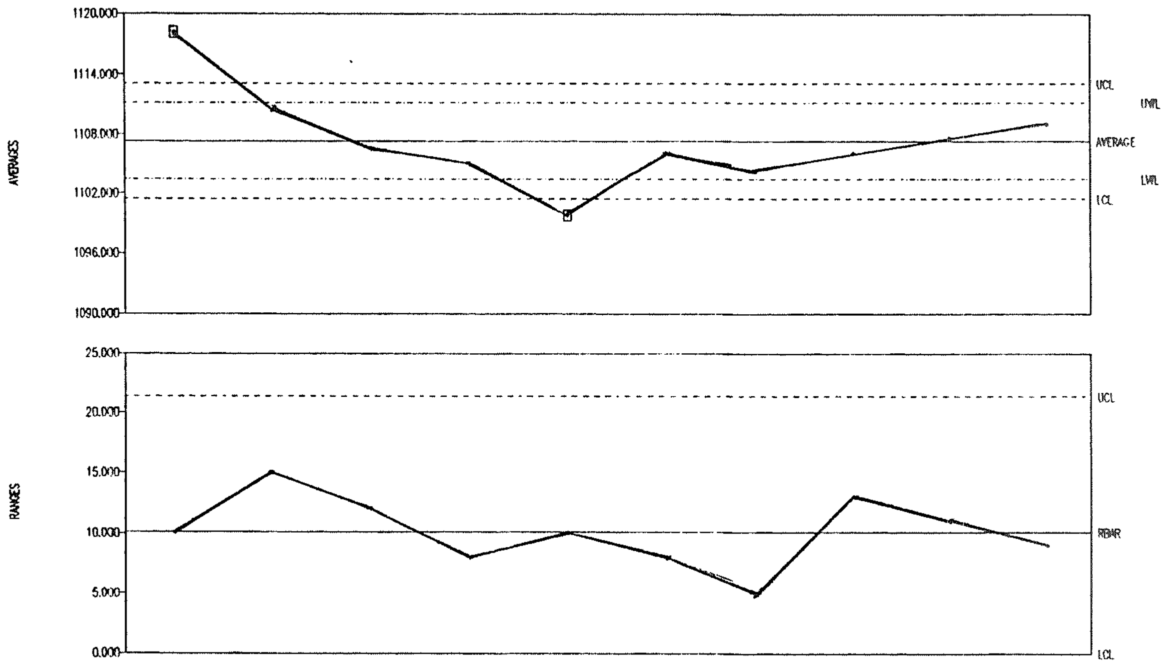

FIGURE 7. $\overline{X}$ and R Chart of Sample Hydraulic Pressure Data